Numerical Models & Analysis

Hydraulic & Hydrologic Considerations in Planning

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Objectives

- **Be able to:**
  - **Explain the importance of modeling & analysis in water resources management**
  - **Identify model types**
  - **Discuss model inputs/outputs**

H&H Engineering Models

- **Purpose: To simulate and analyze physical processes, explore scenarios or do alternative analyses, and assist the decision makers in selecting from alternatives**

- **H&H model results are used in many other types of models (e.g. sediment & nutrient transport, biological response models, statistical analysis)**

- **Types:**
  - **Rivers**
  - **Coastal**
  - **Watersheds**
  - **Reservoirs & Lakes**

Planning Models

- EC 1105-2-407 provides the following definition of a planning model:

"any models and analytical tools that planners use to define water resource management problems and opportunities, to formulate potential alternatives to address the problems and take advantage of the opportunities, to evaluate potential effects of alternatives and to support decision-making."

Certification of Models

- **Currently no certification of Engineering Software required**
- **Engineering & Construction (E&C) – Science & Engineering Technology (SET) addressing engineering models & software**
- **EC 1105-2-407, Planning Models Improvement Program: Model Certification**
  - **EC specifically for software used in USACE planning studies**
  - **Makes a distinction between "planning models" and "engineering models used in planning studies"**

Computer models are based on

- data
- program algorithm (ie. model structure)
- user experience & judgment

Garbage In/Out

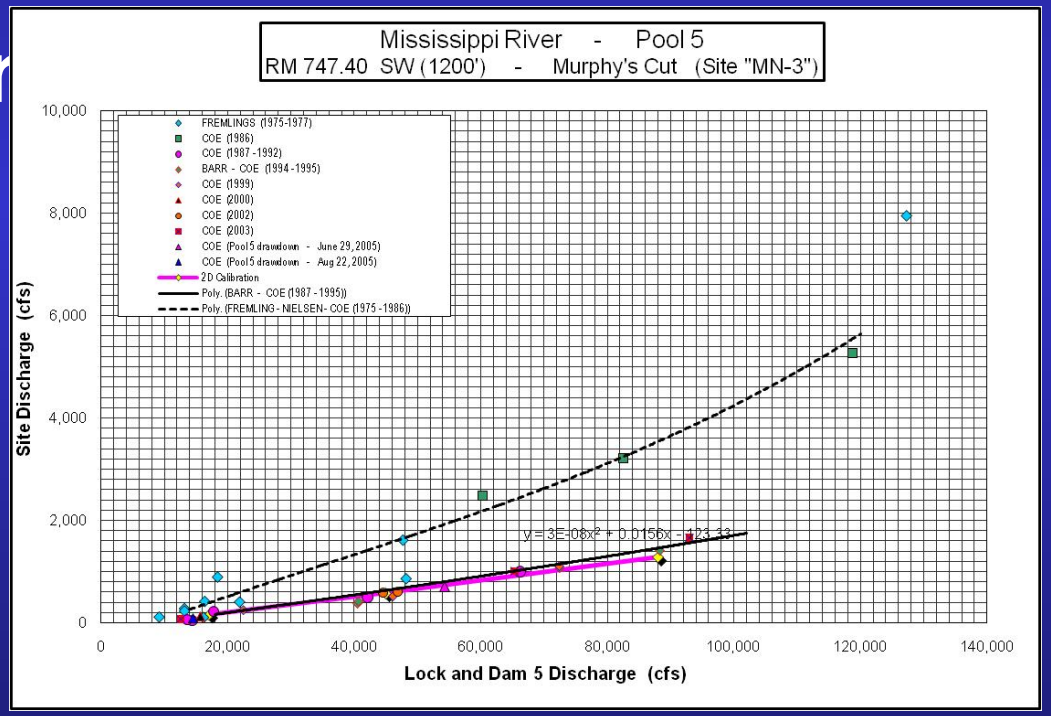
- **Need interpretation - not blind acceptance of outputs**

“Models are for providing insight, not answers”

- Tony Thomas

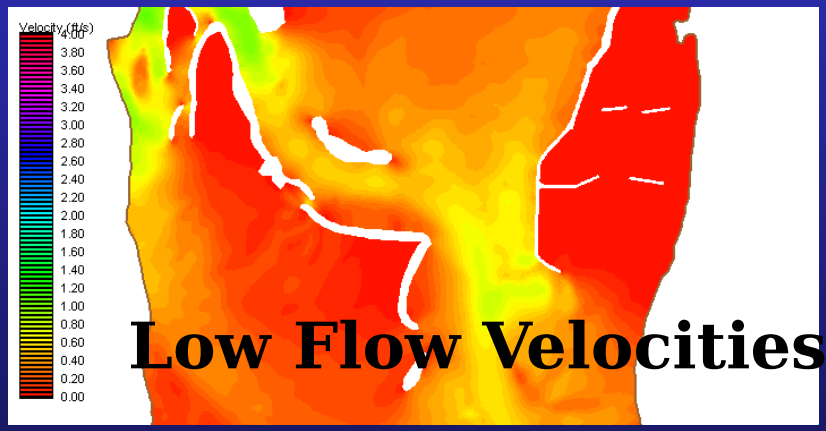
Internal analysis steps

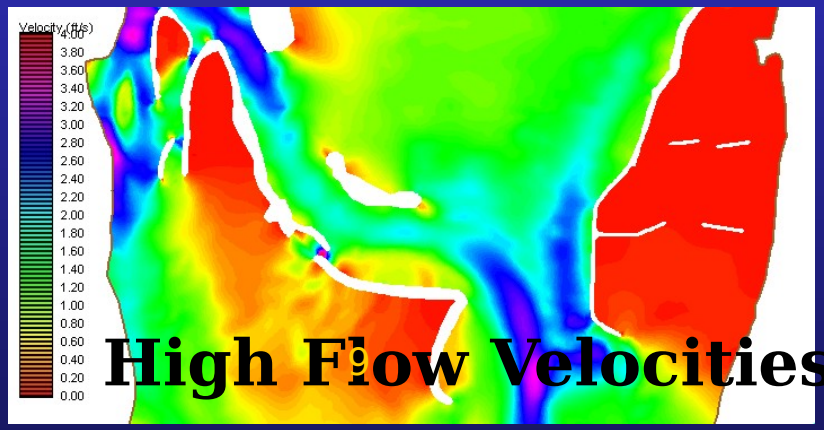
- calibration
- validation
- iteration



Physical representation by models

- spatial variation
- temporal variation





Modeling Steps

- **Modeling Existing Conditions – about 50-70% of Effort**
  - Data Collection
  - Initial Model Setup
  - Calibration/Verification to Existing Conditions
- **Modeling Future Without Project Conditions – about 10-20% of effort**
- **Alternative(s) Modeling – about 10-20% of effort**
  - Iterative Process to optimize designs
  - Involves initial hydraulic design of features – about 10-20% of effort
- **Comparison of With and Without Project Conditions**
  - Stage Reductions from Alternatives
  - Impacts to Study Area/Watershed Hydrology & Hydraulics and Ecosystem

Model Sources

- **Corps' Hydrologic Engineering Center in Davis, California – HEC series (HEC-HMS, HEC-RAS, etc.)**
- **Engineering Research & Development Center – ERDC (ADH, CH3D, etc.)**
  - **System Wide Water Resources Program (SWWRP)**
    https://swwrp.usace.army.mil/
- **Private Sector and Academia (MIKE, ADCIRC, etc.)**

Science & Engineering Technology (SET) Initiative

- **Engineering & Construction (E&C) – Science & Engineering Technology (SET) addressing engineering models & software**
  - Conducting inventories & assessments of model software in use
  - Developing process to document quality of commonly used models
    - ERDC models
    - HEC models
    - Well known & widely used models

- **Focus is on application**
  - Tool Selection
  - Quality of Input Data
  - Model Calibration
  - Verification of Assumptions

Science & Engineering Technology (SET) Initiative

- **Model Categories**
- **Enterprise (Mandated, Required)**
- **CoP Preferred (Preferred Software – Recommended)**
- **Allowed for Use (Niche Software – Good Enough to Share)**
- **Retired (limited functionality, allowed)**
- **Not Allowed for Use (Obsolete or Technically Inadequate Software)**

Enterprise Tools (Mandated, Required)

- S&E Tools: ProjectWise, CWMS, RMS, MS Office Suite, CEFMS, P2. No other tool allowed for use.
- Major resourcing requirements for support and funding
- Business case to National Mgmt Board (NMB) for approval
- Developed by CoP/HQ Sponsor
- Implementation Plan
- Exception to use needs to be approved by NMB

CoP Preferred (Preferred Software Option -- Recommended)

- Example: Microstation
- Software represents single-preferred solution as recommended by CoP-consensus; version should be specified.
- Preferred software for use by virtual teams throughout USACE
- Software assumed to be in use by a large percentage of USACE personnel with need for this requirement.
- Software allowed for use without additional approval and documentation.
- If software from this list is not selected, the alternate software selected should come from the "Allowed for Use" list or be coordinated with CoP

Allowed for Use (Niche Software -- Good Enough to Share)

- Alternate software that provides similar capability to existing CoP endorsed package or provides unique analysis capability.
- Supports specialized technical or local requirements, or required by customer.
- Category included that permits flexibility to ensure people can accomplish their missions.
- Software must be recognized as technically viable approach by industry acceptance or some certification/validation process.
- The decision to select software from this list is made locally and rationale for selection should be described in study/design documentation.

Retired

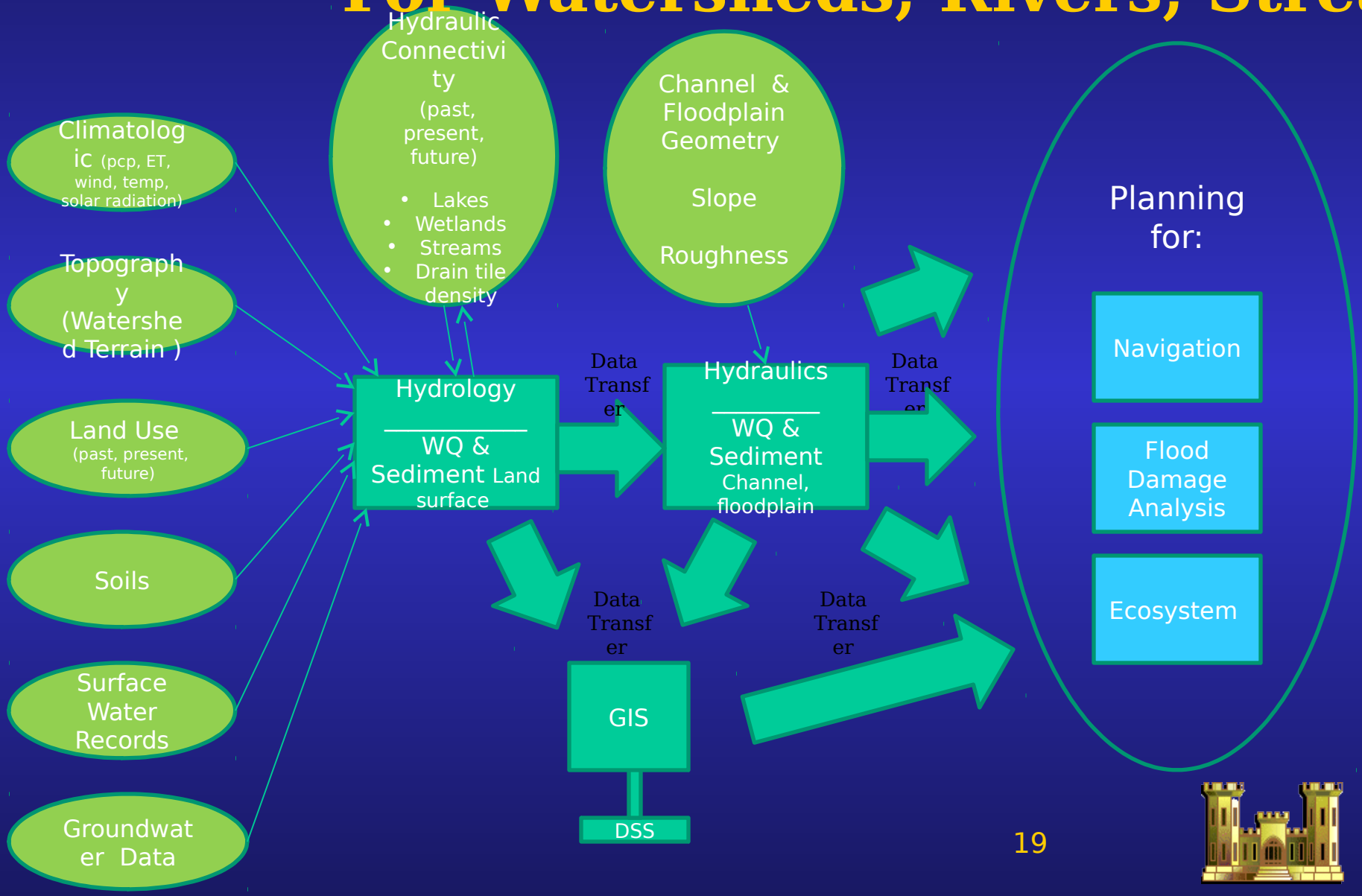
- Software determined by CoP technology review to have more limited functionality compared to similar tools listed on "Preferred" or "Allowed for Use".
- Software does not best fulfill the needs of the technical functions or requirements.
- Obsolete program but still needed for "niche" mission requirements; should be reviewed by CoP for upgrading.
- Example: HEC-1 or HEC-2 models developed for previous studies but never converted to HEC-HMS or HEC-RAS

Not Allowed for Use

Summary
Model Selection

- When possible, use Mandated or Preferred Software
- If other Software is being used, obtain consensus of Vertical Team ASAP during study
- ATR and/or IEPR should review the use and applicability of non-standard software to confirm it is being used appropriately

Hydrologic and Hydraulic Mod
For Watersheds, Rivers, Strea



Hydrologic Modeling:

Routing of rainfall and runoff through watersheds, reservoirs, channels

Hydrograph

Parameters

Hypothetical Storm

Rainfall Event

Loss Rates

(GIS Analysis)

Sub-basin Drainage Areas

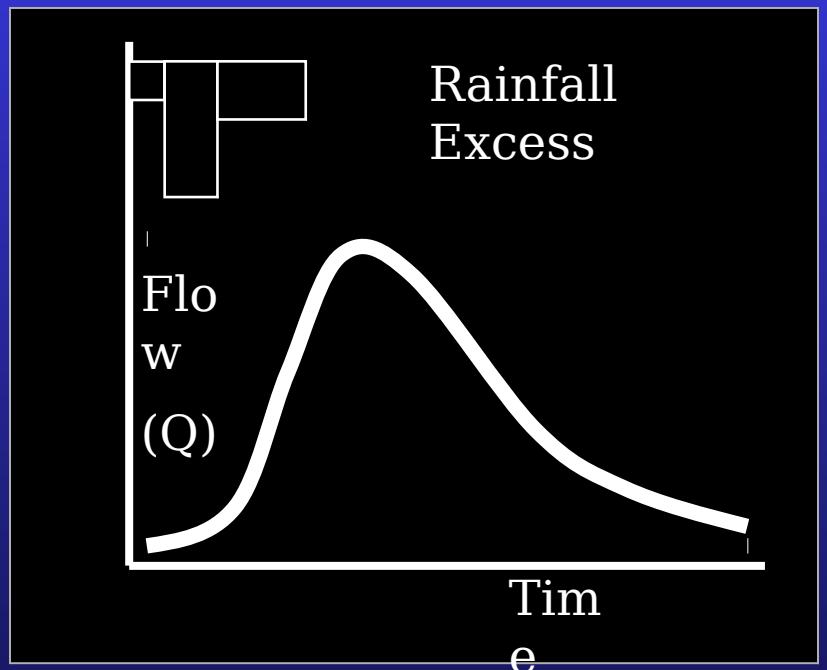
Deterministic or Stochastic

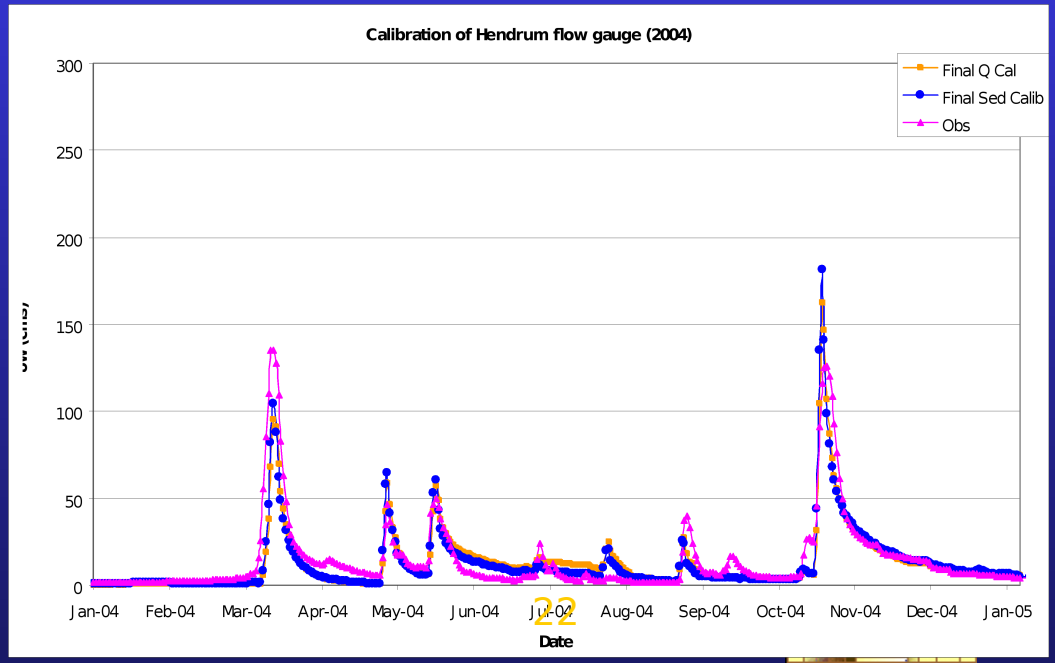
- Deterministic Models. These models try to represent the physical processes observed in the real world. Typically, such models contain representations of surface runoff, subsurface flow, evapotranspiration, and channel flow, but they can be far more complicated. **Deterministic hydrology** models can be subdivided into single-event models and continuous simulation models.

- Stochastic Models. These models are black box systems, based on data and using mathematical and statistical concepts to link a certain input (for instance rainfall) to the model output (for instance runoff). Commonly used techniques are regression, transfer functions, neural networks and system identification.

Hydrologic Modeling Over Periods of Time

- **Single rainfall event**
- **Continuous simulation (for example, day after day for many years)**



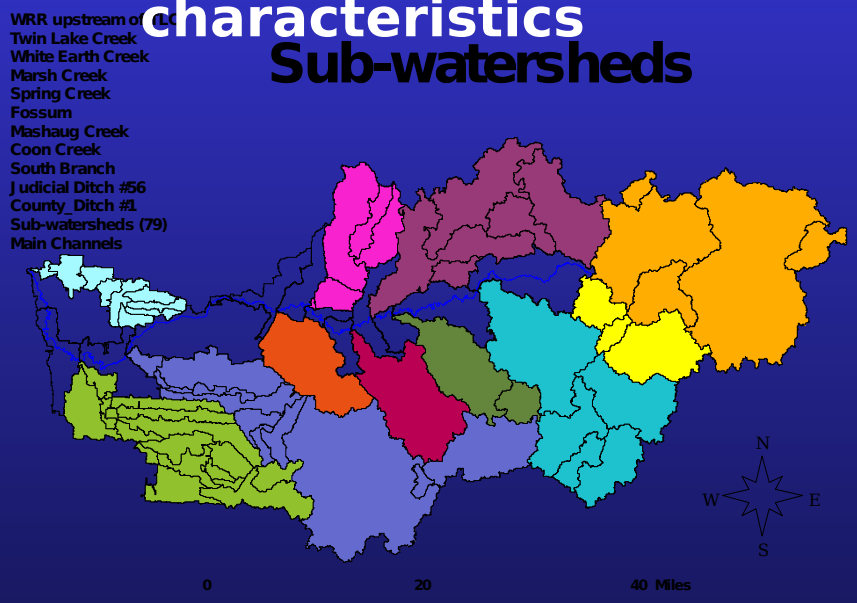


Hydrologic Modeling Over Timesteps

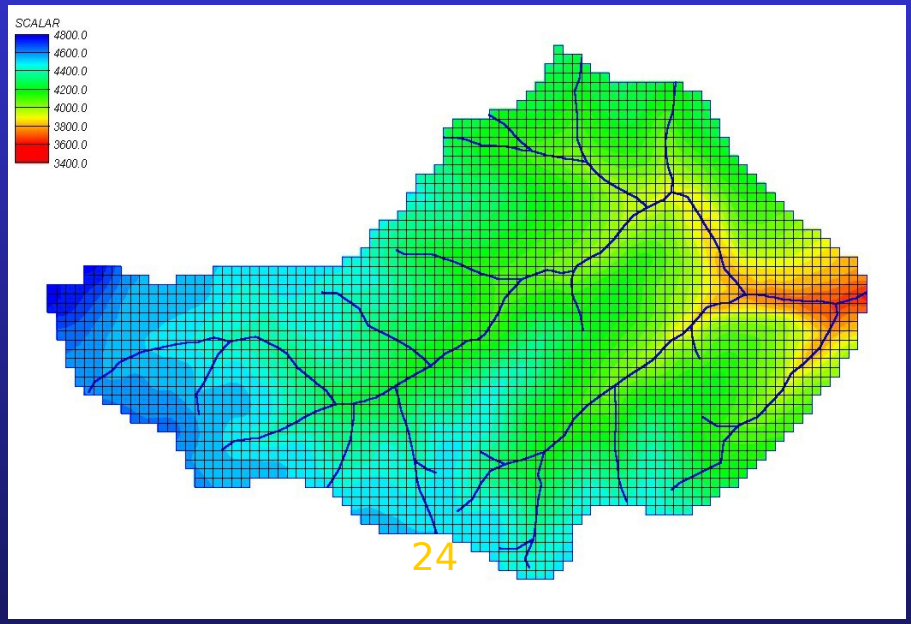
- Timesteps are used for single event and continuous simulation
- The rainfall, runoff, and routing occurring during one time step is calculated

Hydrologic Modeling Over Space

Lumped by subwatershed or areas within a watershed having similar characteristics



Discrete: Watershed is divided into discrete (distinct) areas

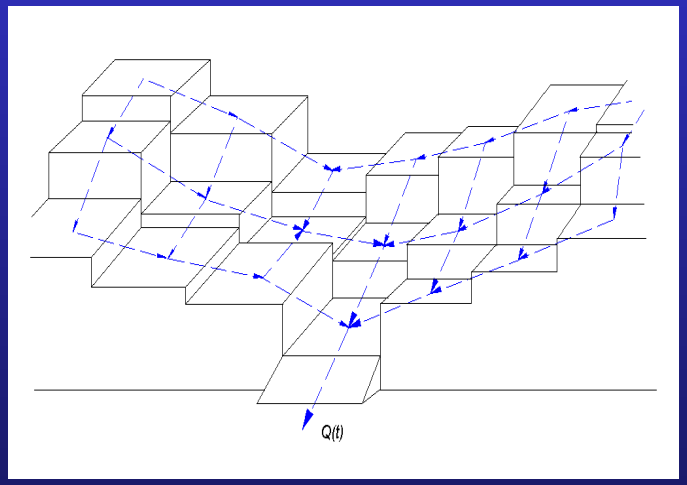


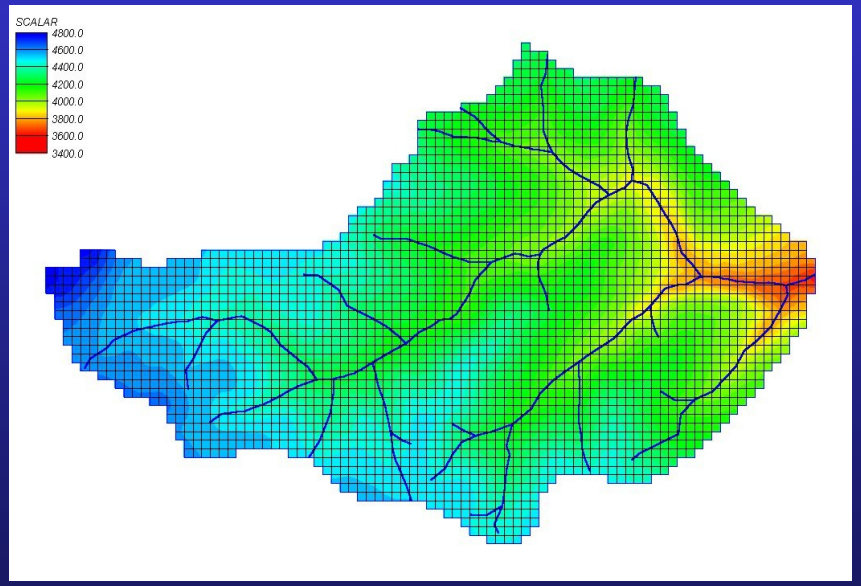
Lumped Hydrologic Modeling Software

- HEC-1
- HEC-Hydrologic Modeling System (HMS)
- Products--hydrographs

Discrete Hydrologic Modeling Software

- Gridded Surface Subsurface Hydrologic Analysis (GSSHA) developed at ERDC
- MIKE SHE - Denmark





Hydraulic Modeling

Rivers and Streams

Discharge

Channel Geometry

Constrictions (bridges, levees)

Roughness

Water Surface

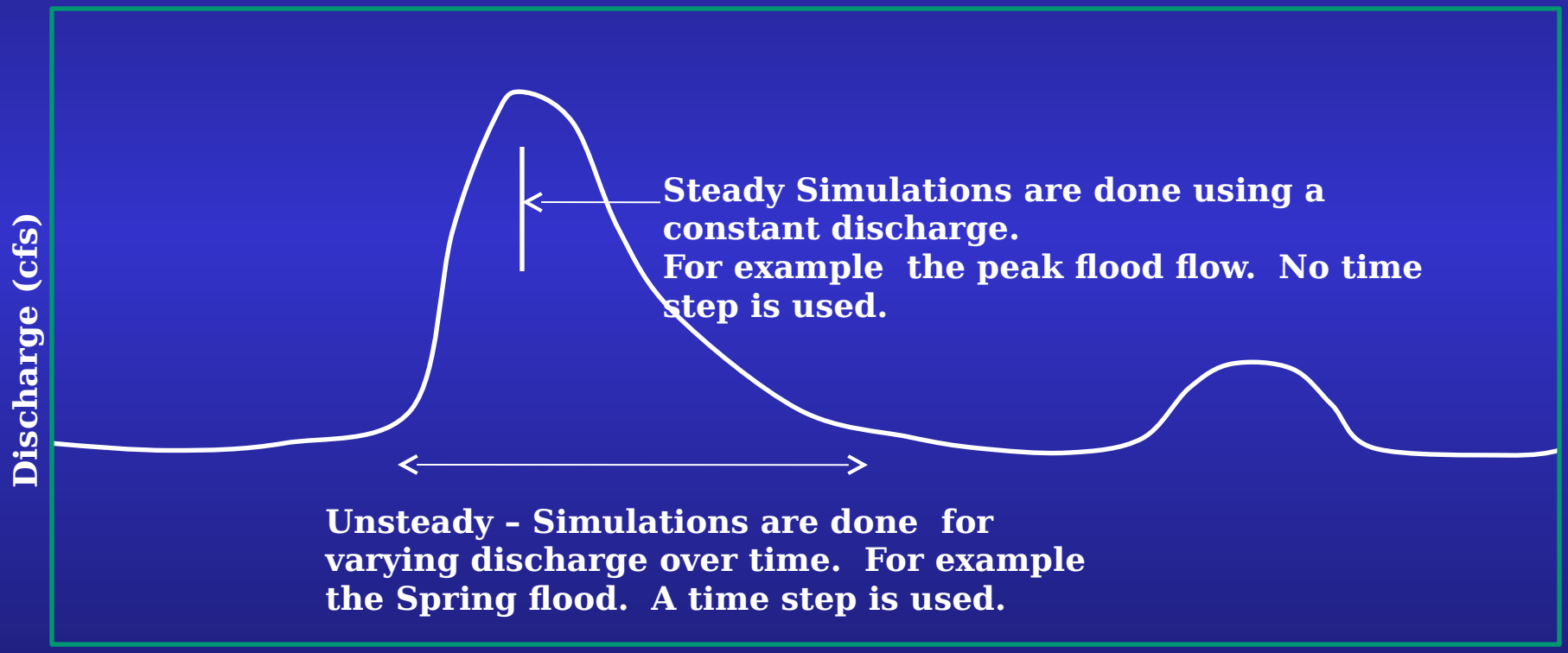
Velocity

Flow Distribution

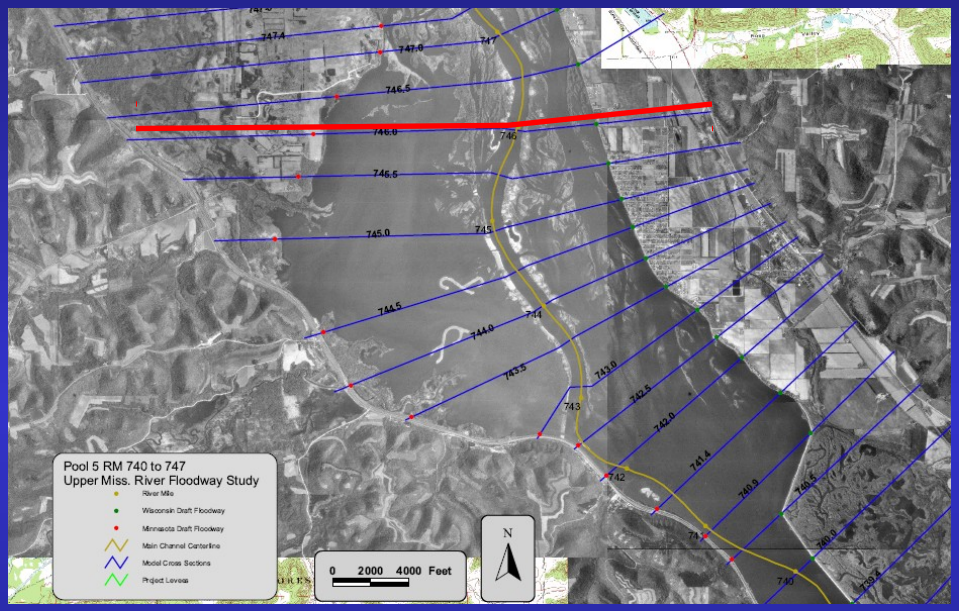
Hydraulic Model Typical Uses (Open Channels)

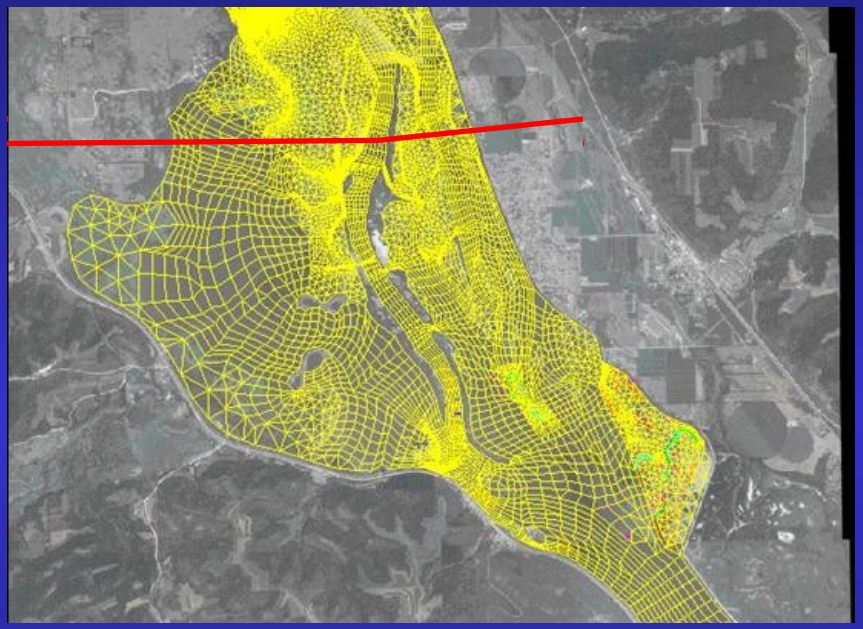
- Capacity /stability flowlines
- Operation & Maintenance options
- Ecosystem physical conditions
- Input to sediment transport models

Hydraulic Modeling over Time
(Steady-State vs Unsteady-State Modeling)


Discharge (cfs)
Steady Simulations are done using a constant discharge.
For example the peak flood flow. No time step is used.
Unsteady – Simulations are done for varying discharge over time. For example the Spring flood. A time step is used.
Jan
April
July
Oct
Dec

Hydraulic Modeling over Space (1D versus 2D)

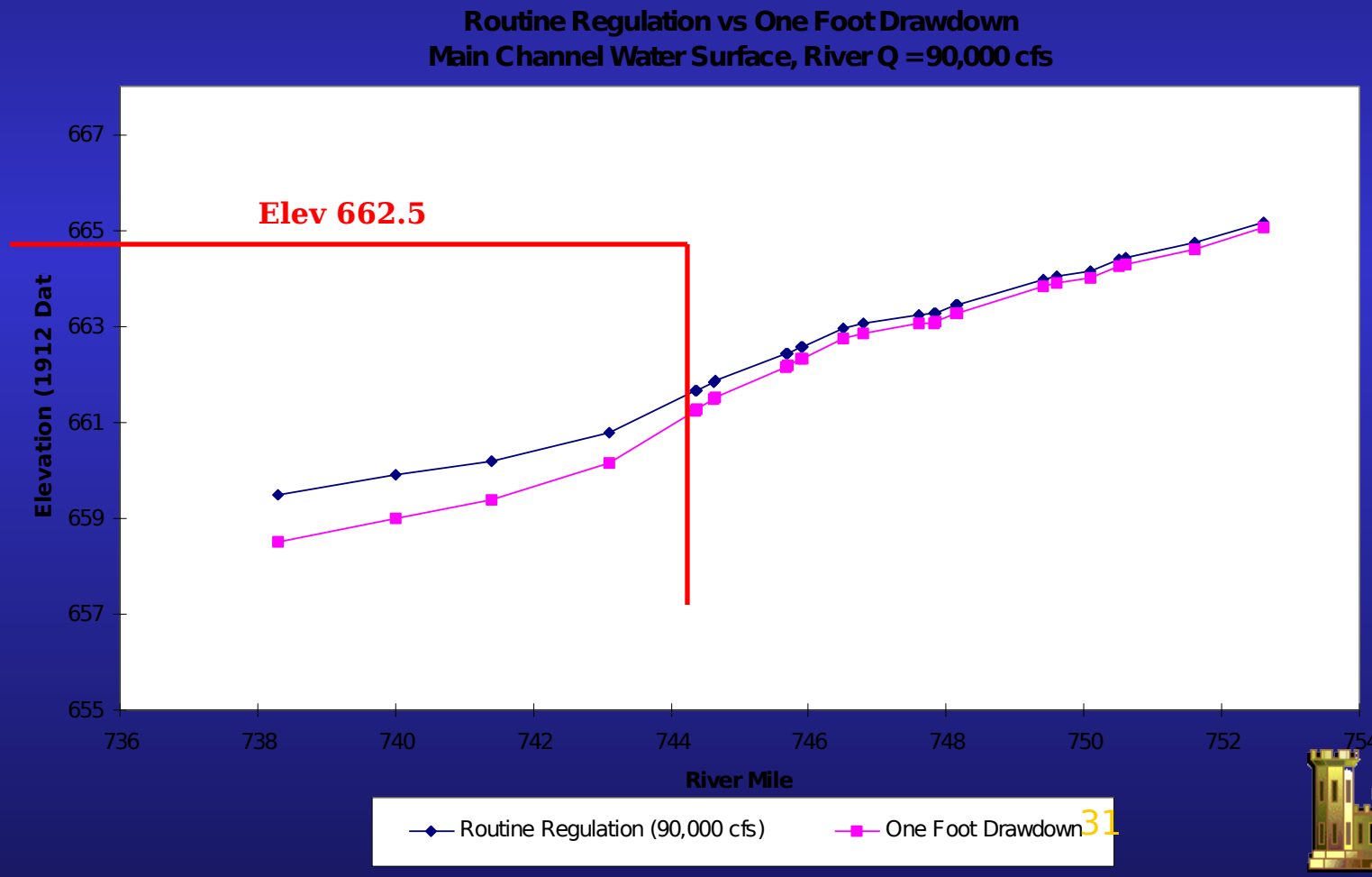


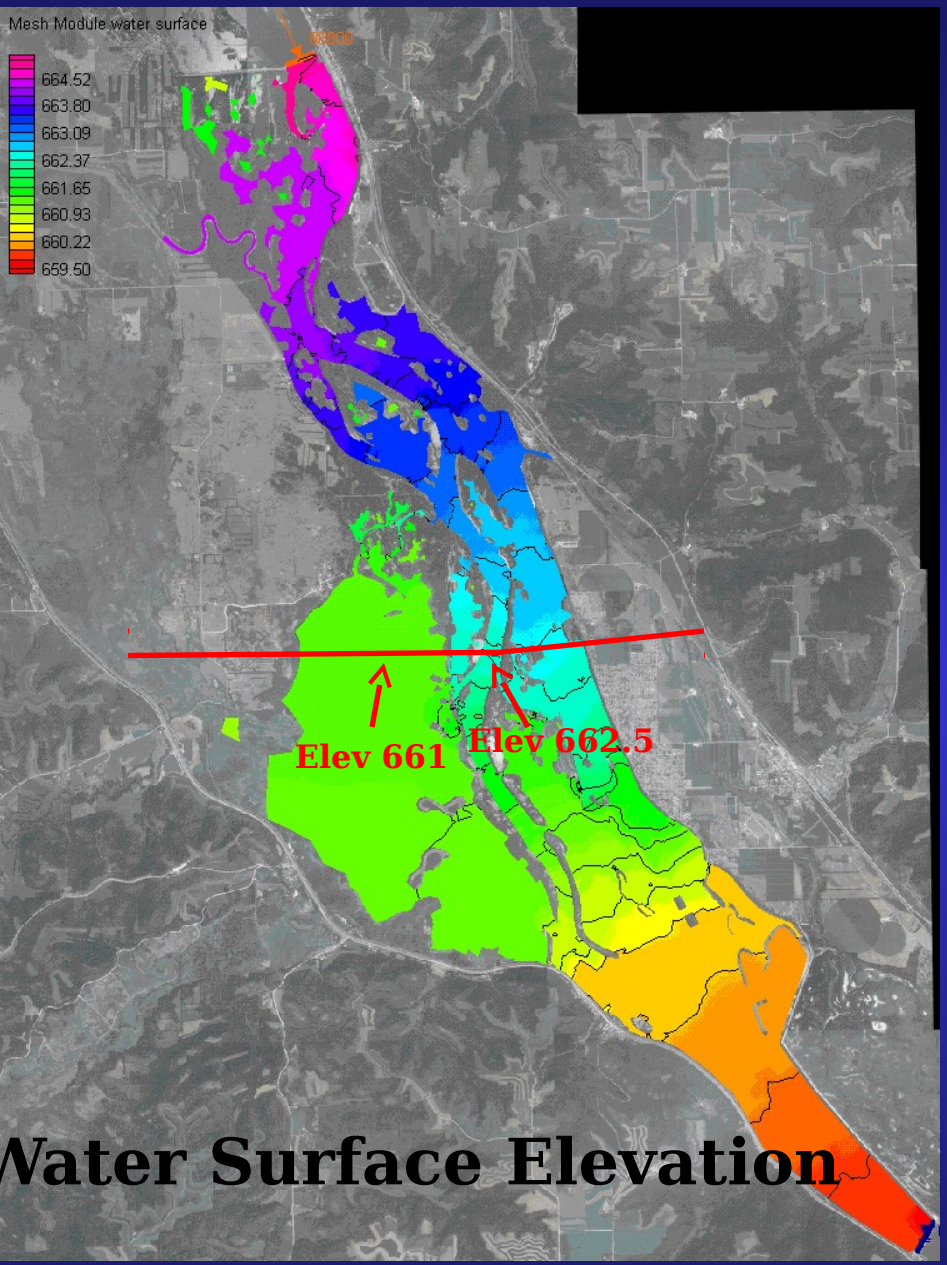


ne-dimensional (1D) models mulate the change in parameters one direction e.g. downstream to upstream)

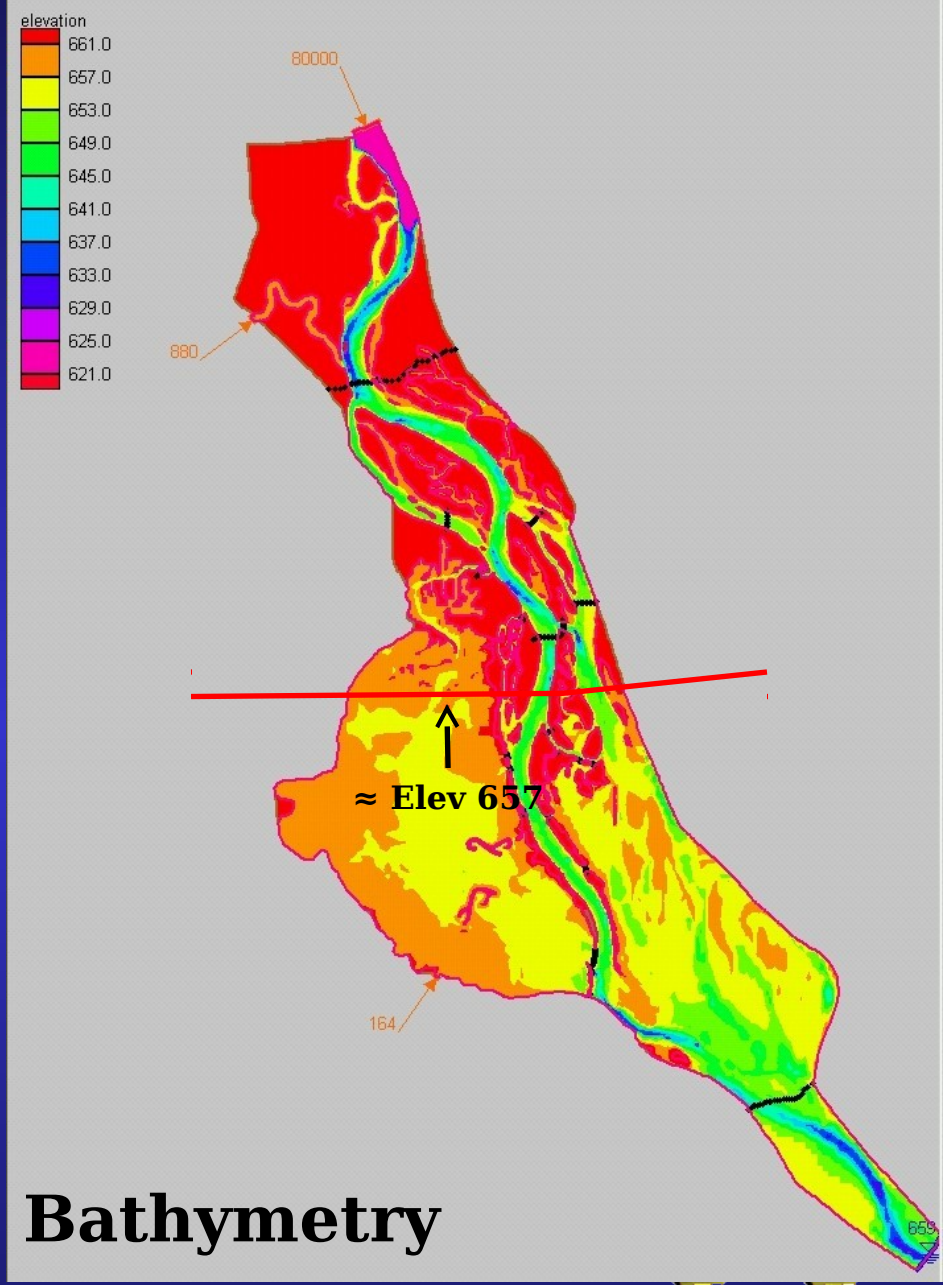
Two-dimensional (2D) models simulate the change in parameters in two direction (e.g. downstream to upstream and from o side of the channel or river valley to the o

1D Model of Water Surface, Pool 5, Upper Miss





Water Surface Elevation



Bathymetry

1-Dimensional Hydraulic Modeling Software (Open Channels)

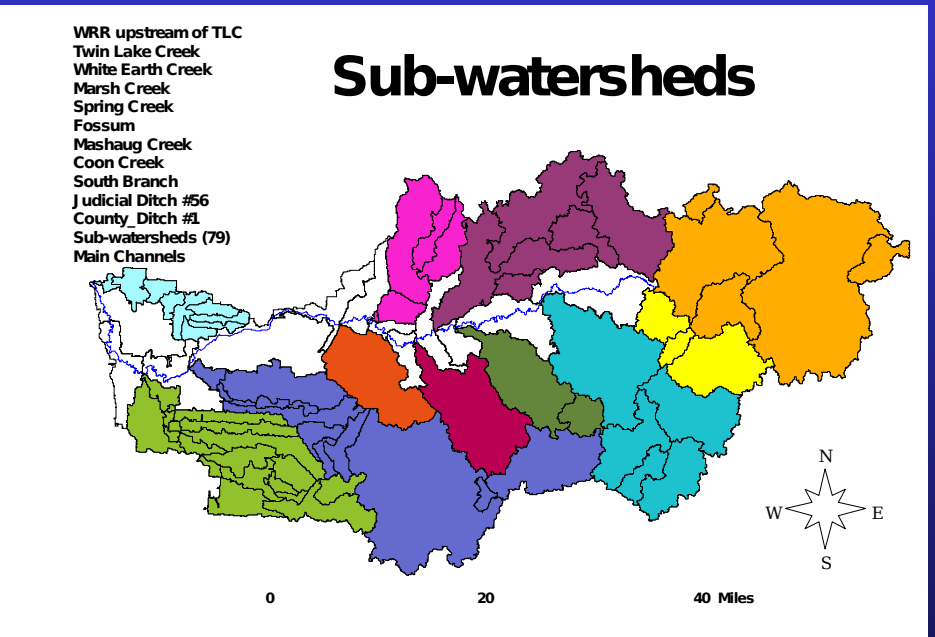
- HEC-RAS (River Analysis System)
- HEC-2
- WSPRO (Federal Highways)

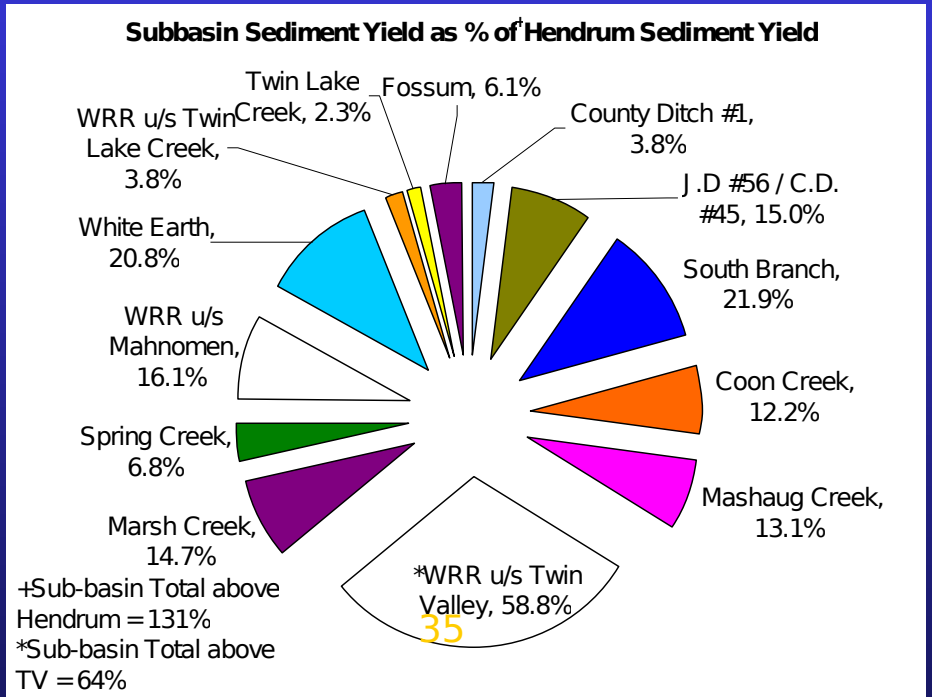
2-Dimensional Hydraulic Modeling Software (Open Channels)

- ADH (Adaptive Hydraulics) developed at ERDC through the SWWRP
- FESWMS (Federal Highways)

Sediment Transport Modeling (Watershed Scale)

- Hydrologic watershed runoff models that simulate both runoff and water quality parameters.



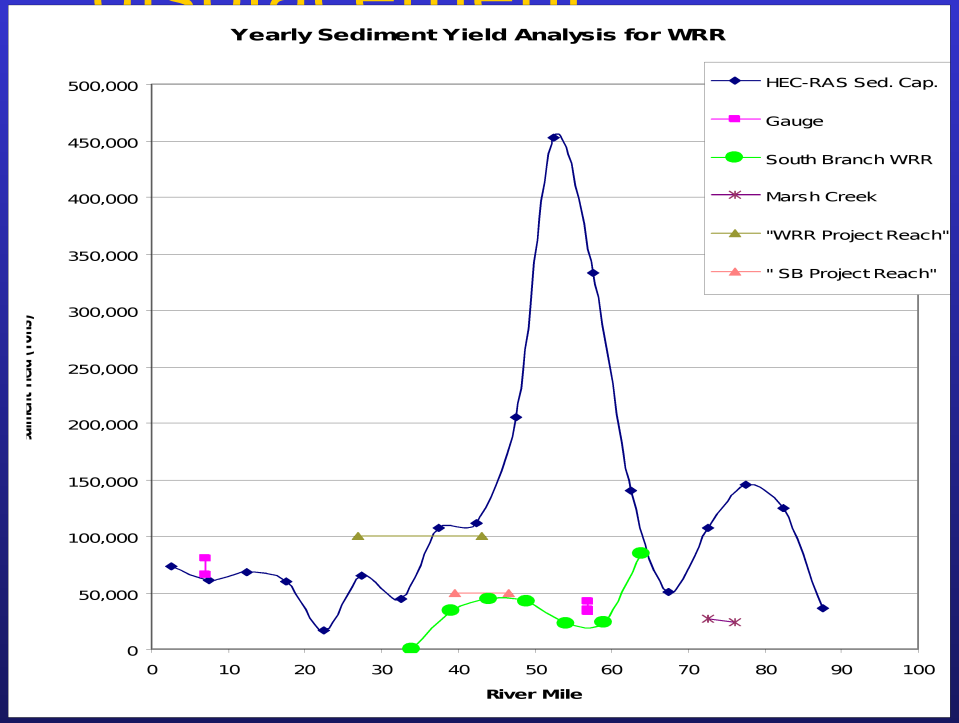

Subbasin Sediment Yield as % of Hendrum Sediment Yield
Twin Lake Creek, 2.3%
Fossum, 6.1%
County Ditch #1, 3.8%
WRR u/s Twin Lake Creek, 3.8%
J.D #56 / C.D. #45, 15.0%
White Earth, 20.8%
South Branch, 21.9%
WRR u/s Mahnomen, 16.1%
Coon Creek, 12.2%
Spring Creek, 6.8%
Mashaug Creek, 13.1%
Marsh Creek, 14.7%
*WRR u/s Twin Valley, 58.8%
+Sub-basin Total above Hendrum = 131%
*Sub-basin Total above TV = 64%

Watershed Sediment Transport Modeling Software

- GSSHA (USACE, ERDC)
- HSPF (US EPA)
- SWAT (USDA-ARS)
- MIKE-SHE

Sediment Transport Modeling (River Scale)

- Hydraulic models that simulate hydraulic parameters, sediment transport capacity, and bed displacement



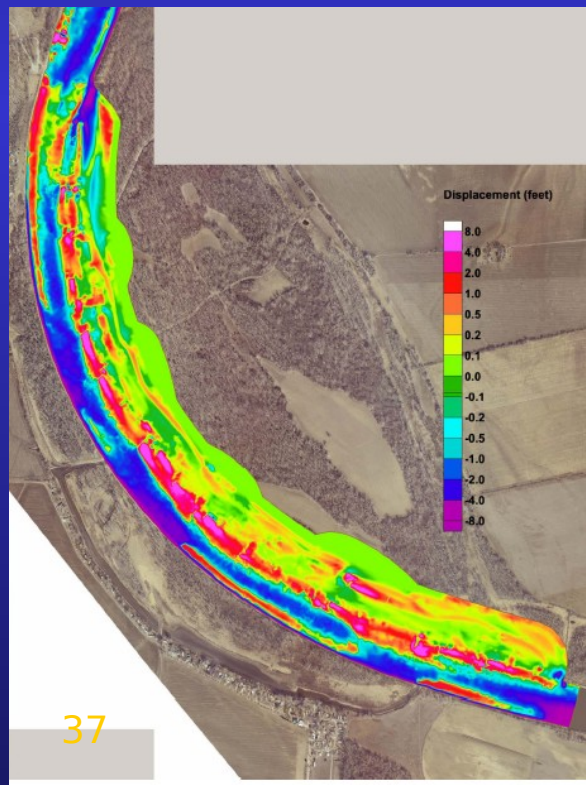


Figure 47: Bed Displacement for the 1997 Hydrograph, Option D

Sediment Transport Model Typical Uses in Rivers

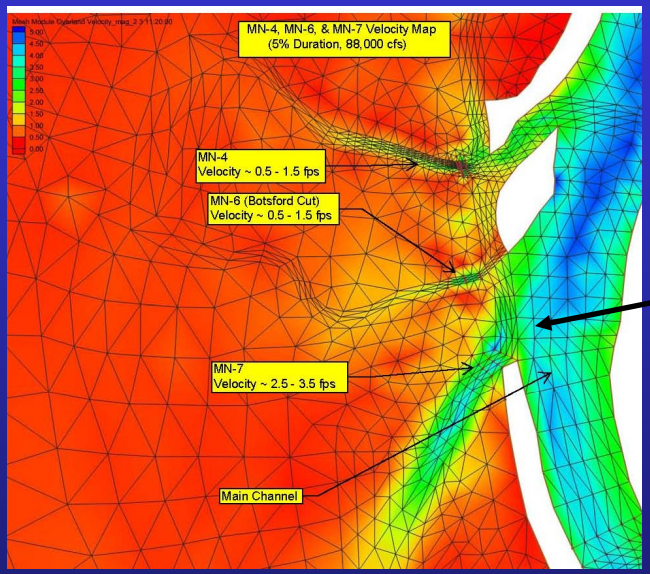
- Channel stability
- Dredging requirements
- Water quality
- Pump station & diversion design
- Maintenance
- Ecosystem restoration

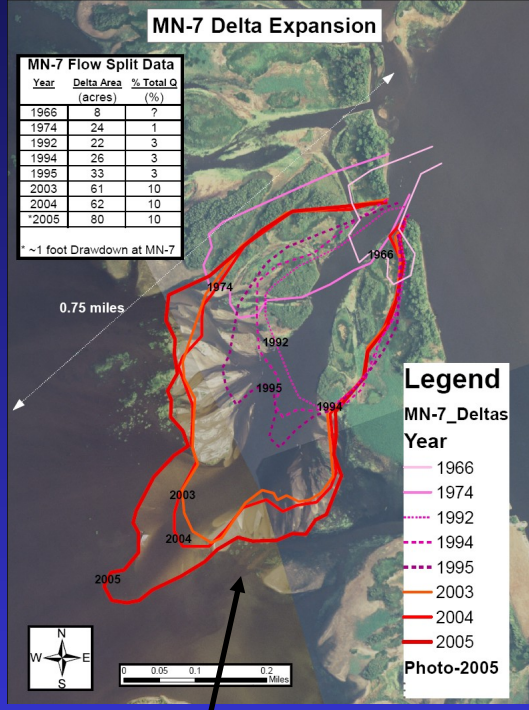
Channel Sediment Transport Modeling Software

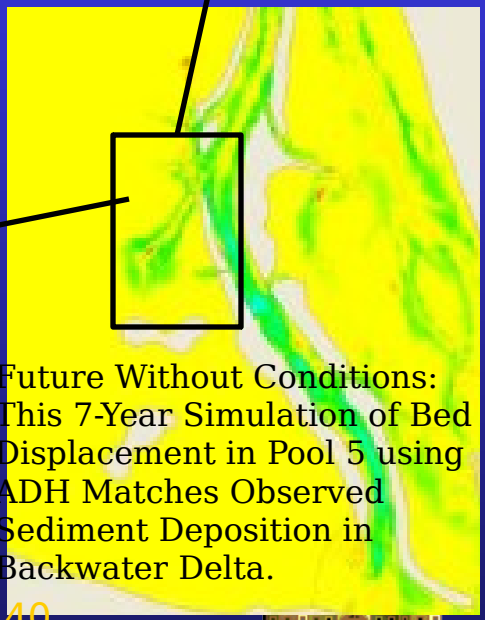
- HEC-6
- HEC-6T
- HEC-RAS (with sediment)
- ADH

Forecast Future Without-Project Conditions

2D models are evolving to the point where patterns of erosion and deposition can be predicted. This allows the user to interpret future conditions given various hypothetical flow conditions. The effects of large floods can be analyzed also.







Future Without Conditions: This 7-Year Simulation of Bed Displacement in Pool 5 using ADH Matches Observed Sediment Deposition in Backwater Delta.

Statistical Model Typical Uses

- Frequency
- Duration
- Timing
- Stochastic flow simulation

Statistical Modeling Software

- **HEC-FFA (frequency)**
- **HEC-EFM (Ecosystem Functions Model)**
- **IHA (Indicators of Hydrologic Alteration, TNC)**

Model Time and Cost Model Review

- Time and Cost to do the modeling
  - Many factors (1D or 2D, overbank flows, structure complexity) influence this. Here is a few examples
    - UMRS 2D model for 2.5 mile wide river valley, 10 mile reach of river, took 3 to 4 months and 50K.
    - Small River 1D model for sediment budget on 90 mile reach took 2 months and 15K.
    - Culvert analysis 3 days and 2 or 3K
  - Model costs are about 1% of a typical project cost
- Model Review
  - Usually a District Quality Control Function

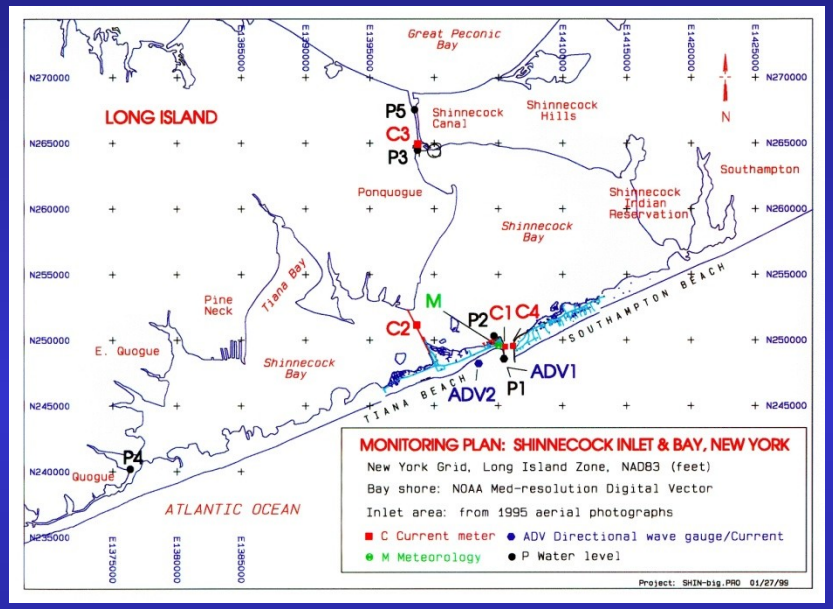
Coastal Models

Coastal Engineering Modeling Considerations

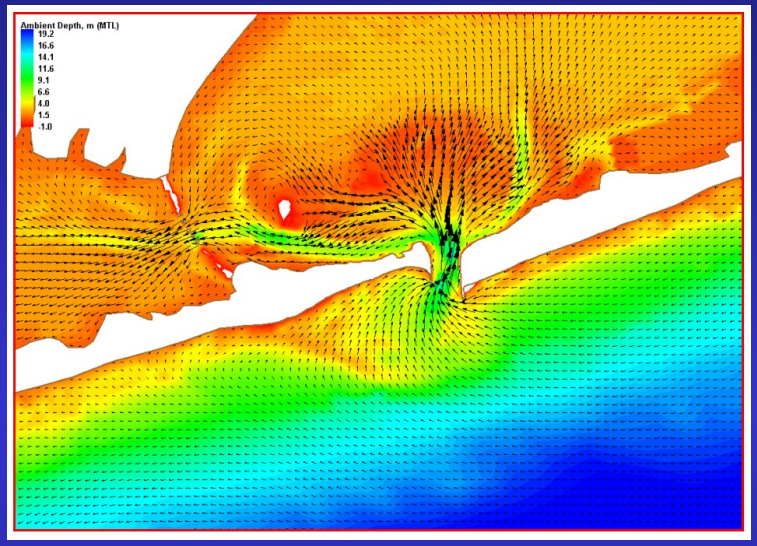
- **$$$**
- **Site Characteristics**
- **Data Gathering**
- **Do we have enough engineering and science to make our results believable?**
- **Cost of Tools**
- **Appropriateness of Design**
- **Stakeholder Issues**
- **Environmental Constraints**
- **State of the art modeling changes over life or large feasibility study**

Remember, show me the $$$

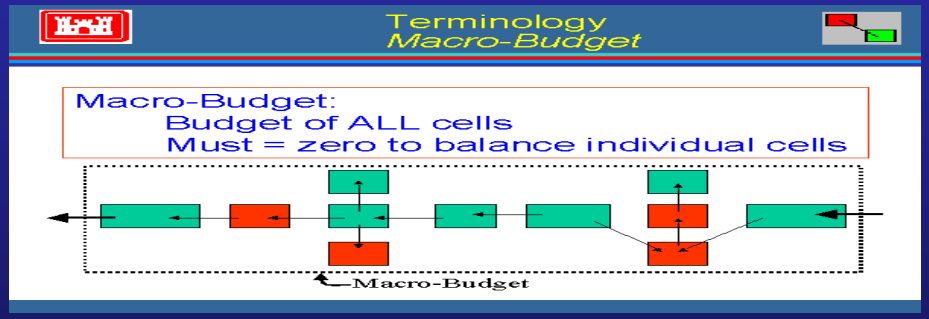
Data Collection & Analysis



? Numerical Models



2. Sediment Budgets



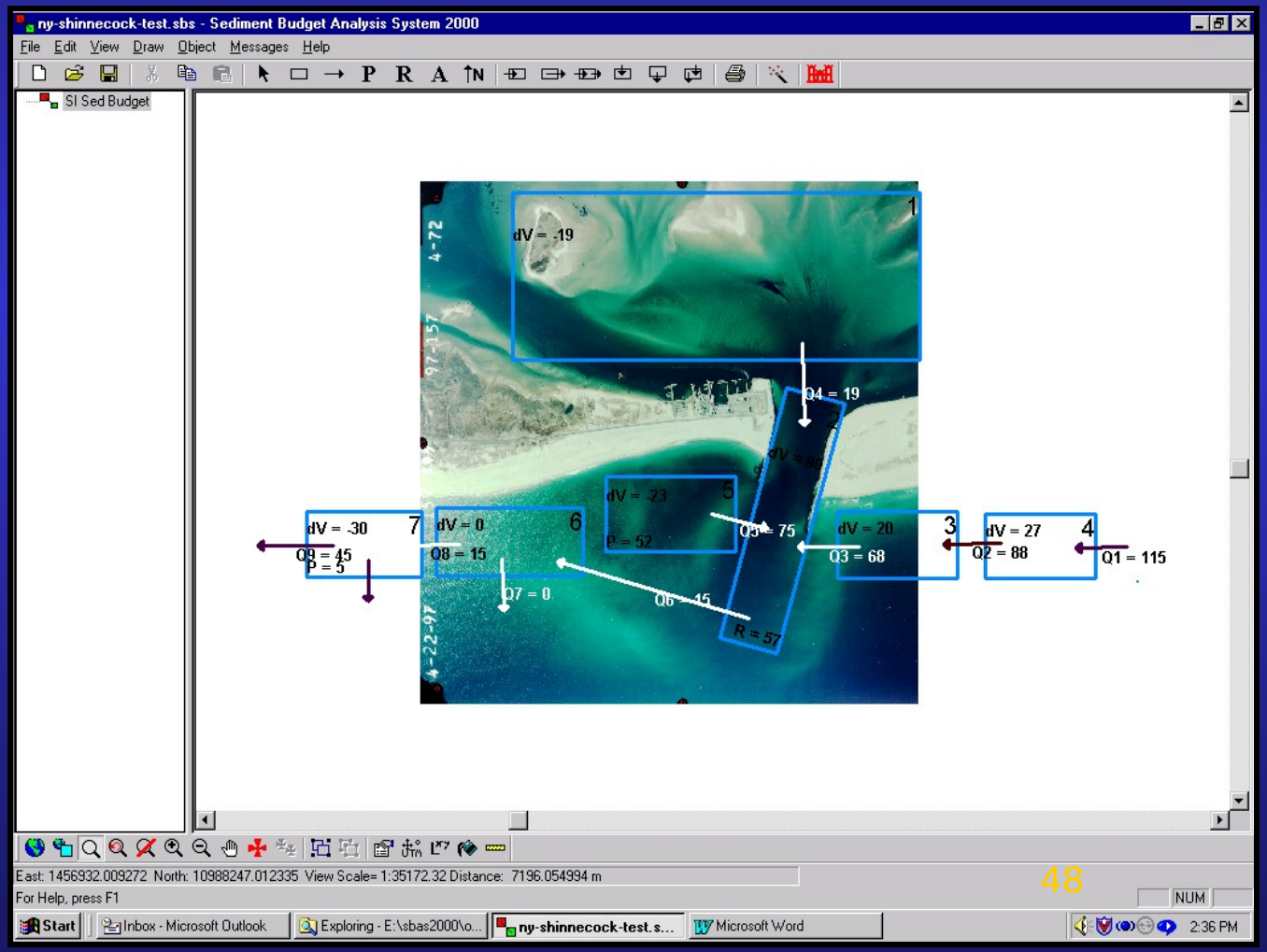
4. Physical Models

H&H Coastal Engineers can model:

- **Sediment Budgets**
- **Wave Climate**
- **Cross-Shore Sediment Transport**
- **Currents and Inlet Processes**
- **Water Levels including Storm Surge**
- **Long-shore Sediment Transport (Shoreline Change)**

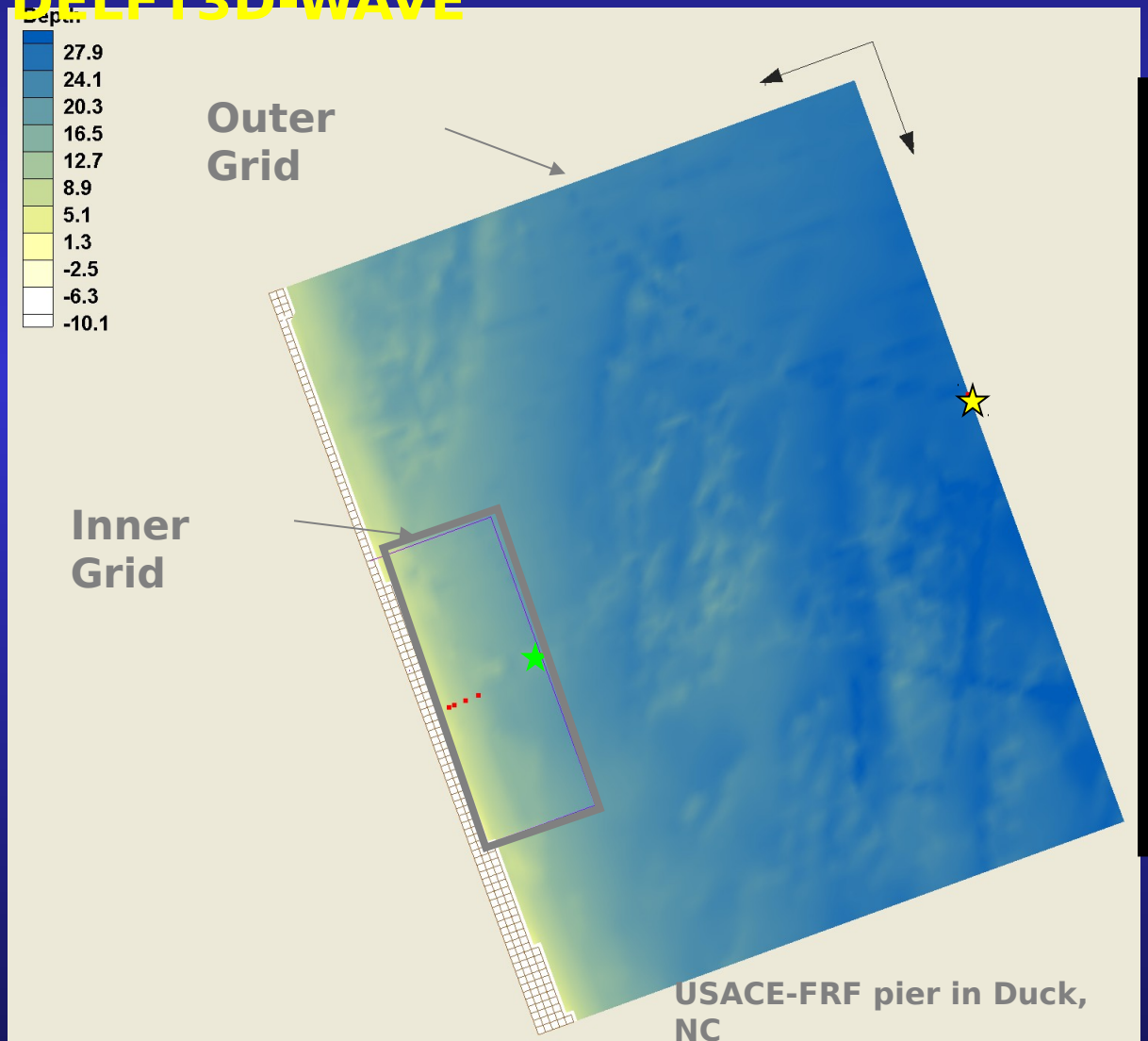
Sediment Budget Modeling

diment Budget Models: SBAS, Excel



Wave Modeling

Nearshore Wave Modeling: STWAVE, CMS-WAVE, DELFT3D-WAVE



Trial Simulation details:

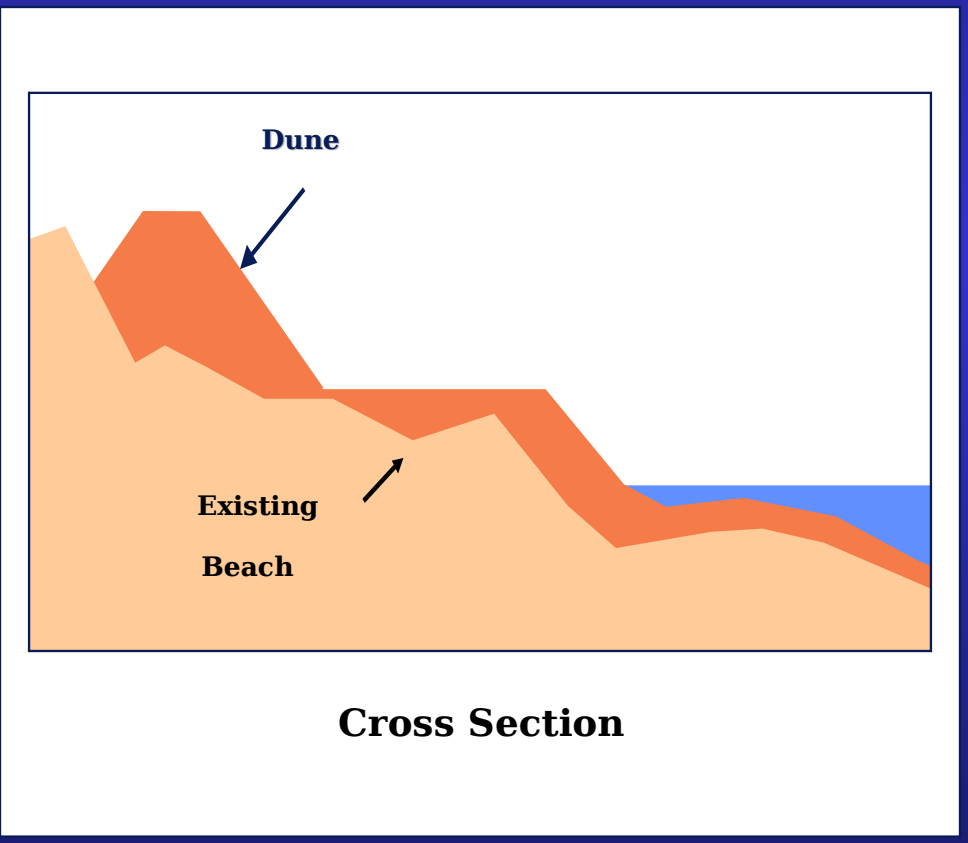
Outer Grid = 200 x 200m
Inner Grid = 100 x 100m
Time Step = 3 hours

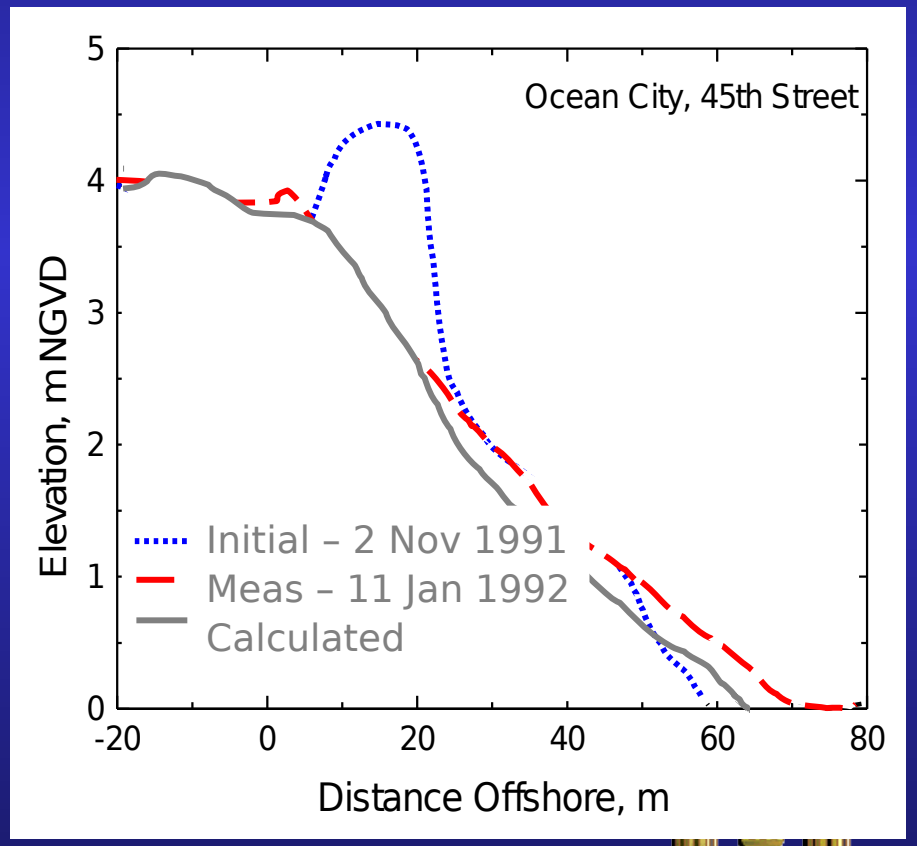
Saved Spectra Locations:

- **CDIP 26 m**
- **Waverider 17 m**
- **AWAC 11 m**
- **AWAC 08 m**
- **AWAC 06 m**
- **AWAC 05 m**

Cross-shore Sediment Transport Modeling

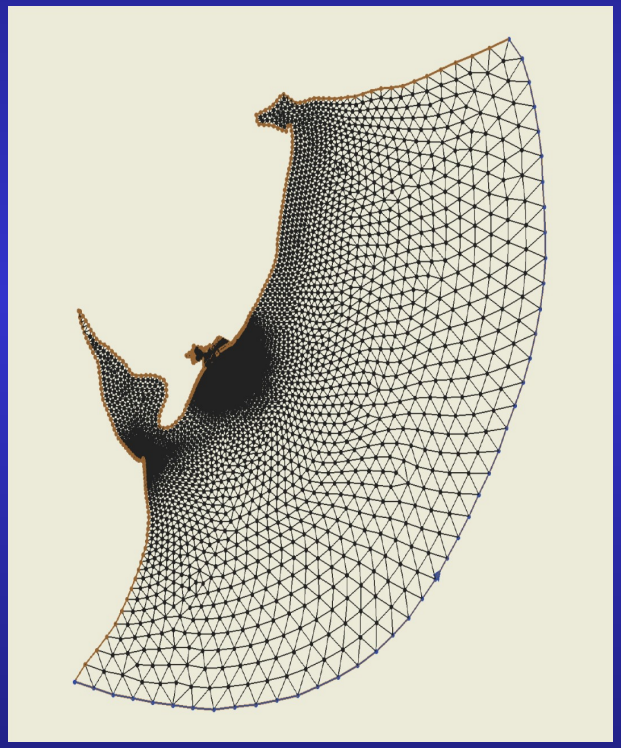
oss-shore Sediment Transport Model: SBEACH





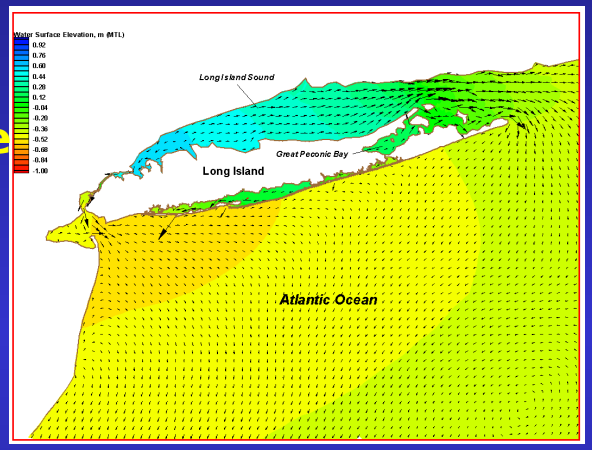
Hydrodynamic (Currents) and Inlet Modeling

rodynamic Model: ADCIRC, CMS-Flow, DELFT3D-Curren

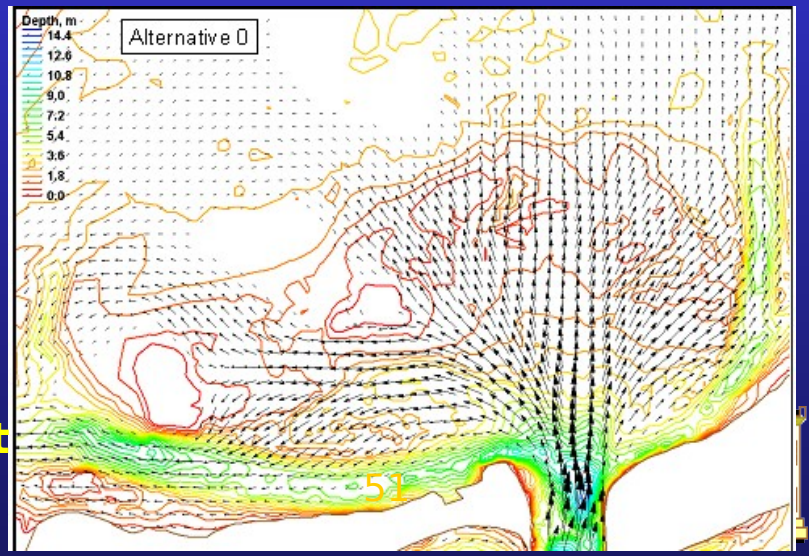


ADCIRC mesh

Propagation of Tidal Wave



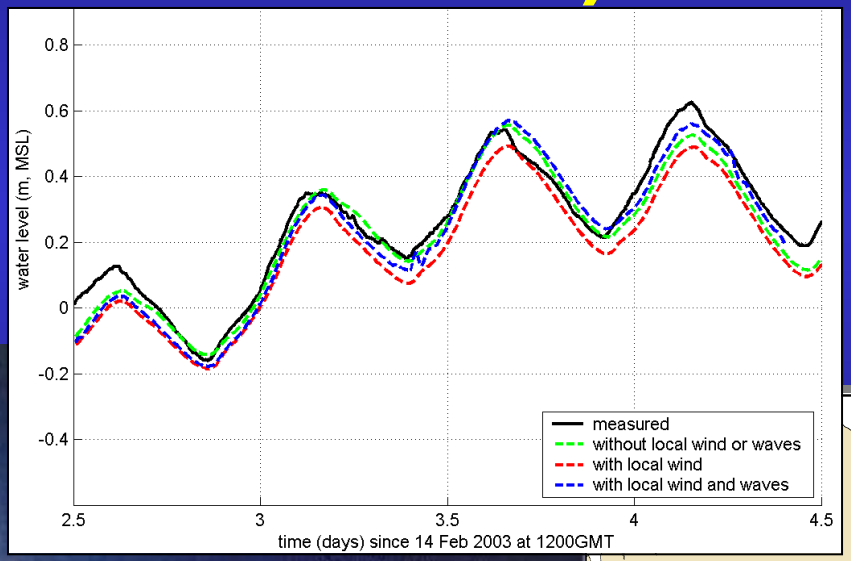
Flood current patterns

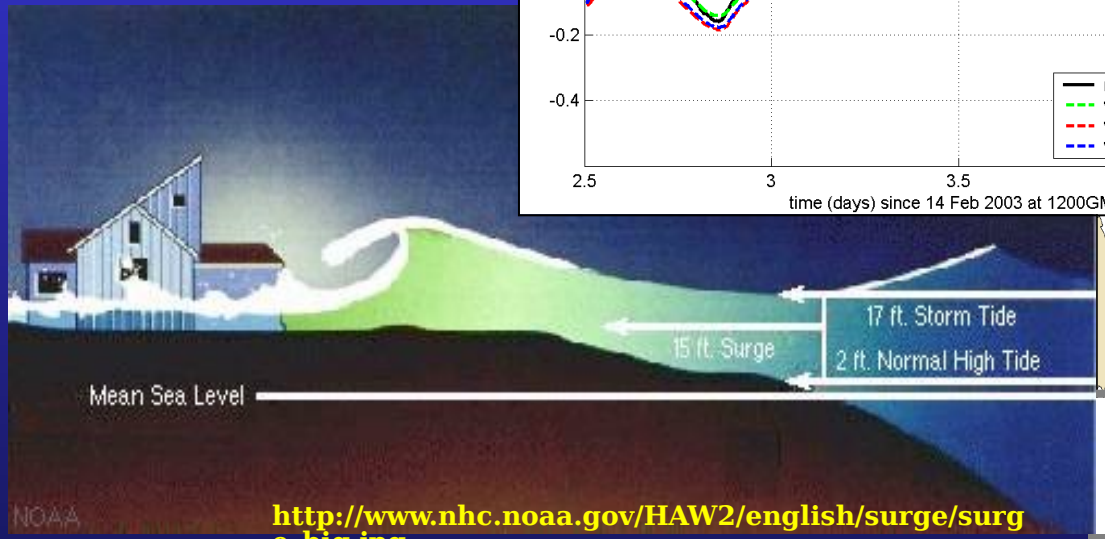


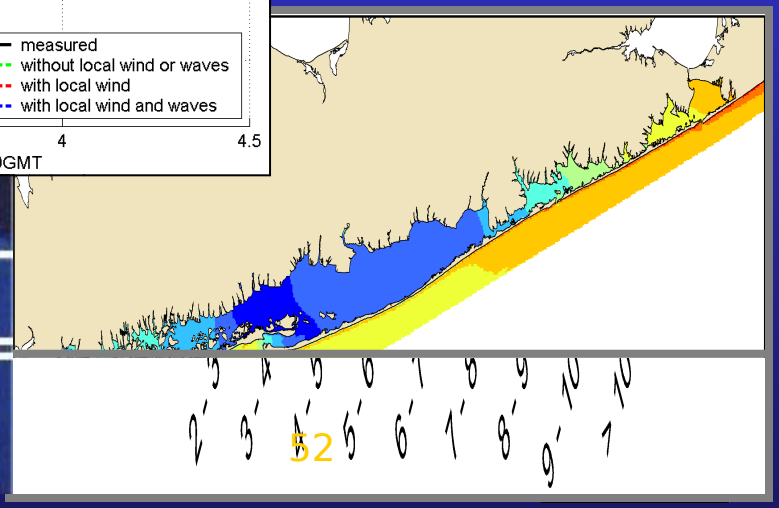
Storm Surge Modeling

torm Surge Model: ADCIRC, DELFT3D

WATER LEVELS (STORM SURGES)


water level (m, MSL)
time (days) since 14 Feb 2003 at 1200GMT
measured
without local wind or waves
with local wind
with local wind and waves

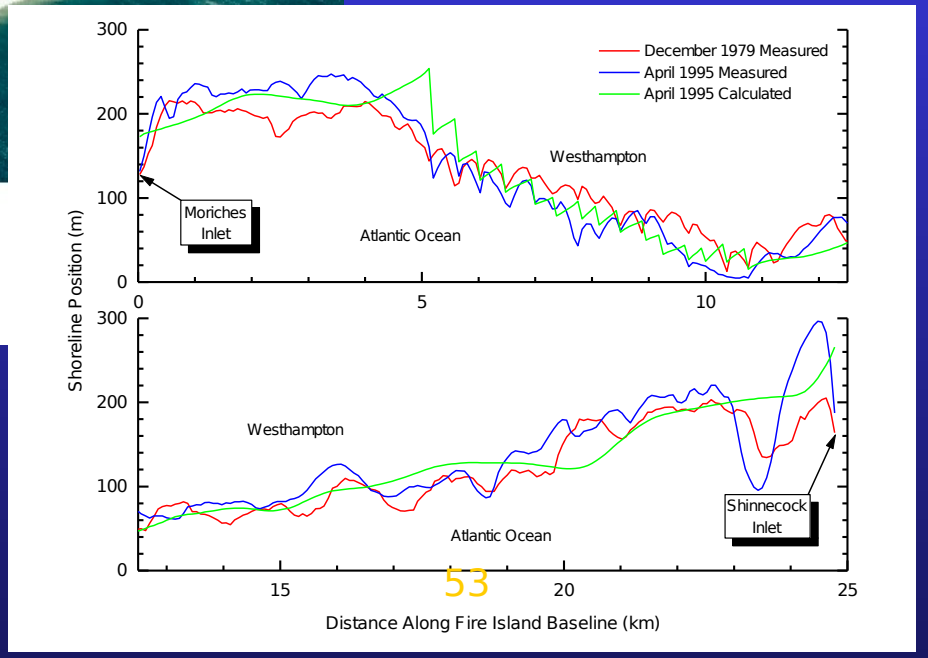




http://www.nhc.noaa.gov/HAW2/english/surge/surge_big.jpg

Longshore Sediment Transport Modeling

ng-shore Transport Model: GENESIS

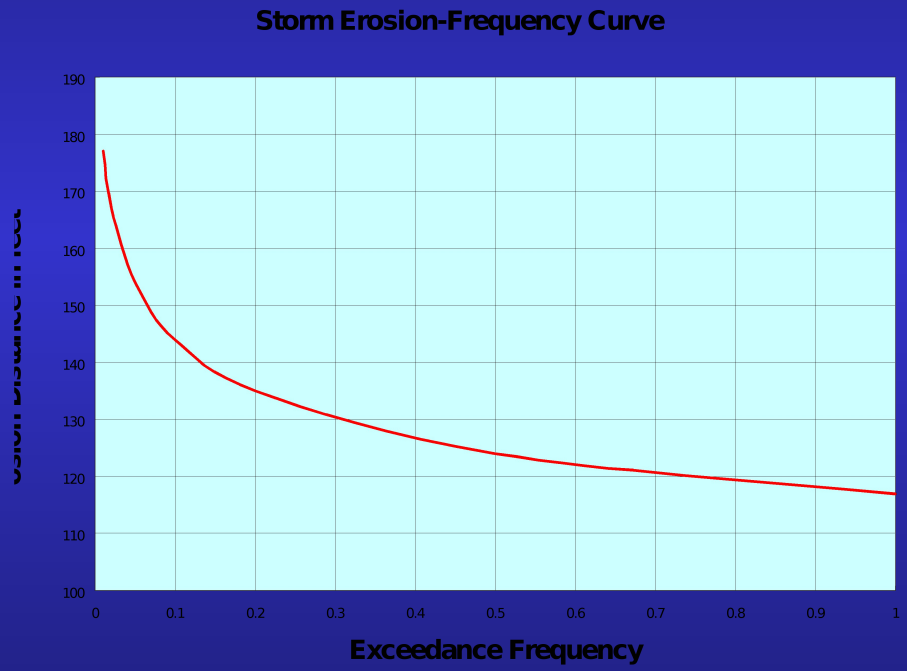


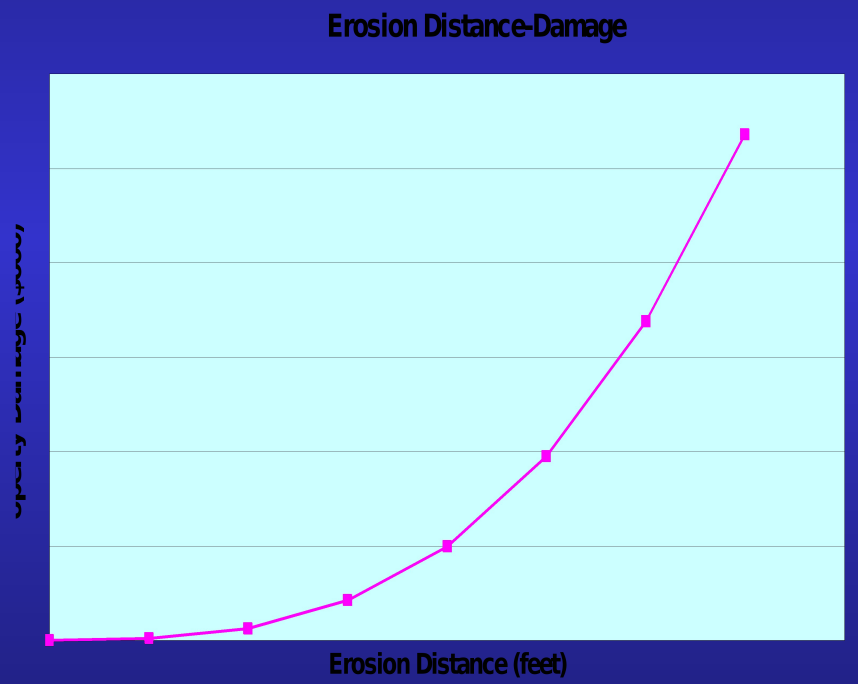
Question - What Storms to Model?

Remember, each computer run can be time consuming (CPU time), thus not possible to model every possible storm scenario

- **SPH – Standard Project Hurricane**
- **Probabilistic Approach – Monte Carlo simulation of all of the storm parameters**

Frequency-Based Approach (Previous)





Flood = Erosion

Erosion = $$$

New Approach (Beach-*fx*)
Event-based Monte Carlo Life Cycle Model

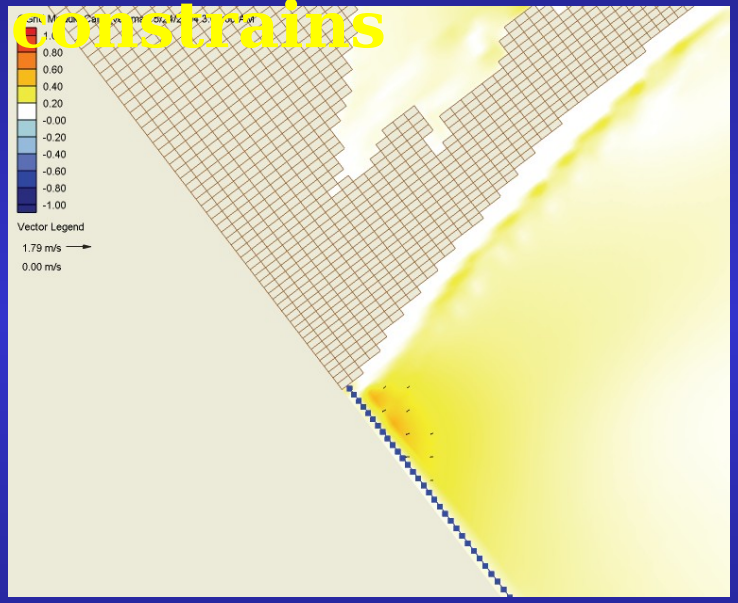
Engineering-Economic Planning Tool for Hurricane and Storm Damage Reduction

Developed to:

- **Address analytical shortcomings of traditional, frequency-based approach**
- **More realistic estimates of life-cycle benefits and costs**
- **Generate science-based information to aid decision making**
- **Develop information to communicate plan performance to stakeholders**

Modeling Limitations

Programming constrains



- Depth Integrated (2D) thus no variation with depth – no possible return flow scenario
- Most circulation models do not include wave setup

Summary

- model is a simplified representation of reality
- common analysis steps

Questions

“Models are for providing insight, not answers”

- Tony Thomas